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Energy balance in Iran's agronomy (1990–2006)

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ABSTRACT

In this study data from 17 years (1990–2006) were collected to determine energy intensive areas and evaluate energy parameters of Iran's agronomy sector. All the direct and indirect inputs of energy for the production of 19 agricultural commodities were evaluated. The inputs and outputs were calculated by multiplying the amounts of inputs and outputs by their energy equivalents. The results indicated that total energy input increased from 32.40 GJ ha^{-1} in 1990 to 37.20 GJ ha^{-1} in 2006. At the same period, total output energy increased from 30.85 to 43.68 GJ ha^{-1}. The results show that irrigation with 40.0% and fertilizer (28.4%) had the highest share in energy consumption. The average net energy gain was a positive value; however, about 87% of the input energy emanates from non-renewable sources of energy. The mean energy ratio was estimated to be 1.07 and showed an increasing trend during the period rising from 0.95 in 1990 to 1.17 in 2006. This indicates that increased use of inputs ha^{-1} in production was accompanied by a larger increase in the output levels. It can be inferred from the results that improvements in irrigation and fertilizer application can significantly affect the energy efficiency of Iranian agriculture.

Contents

1. Introduction

In developing countries like Iran, agricultural growth is essential for fostering the economic development and meeting the ever higher demands of the growing population. Within the past 30 years commercial farming has replaced subsistence farming as the dominant mode of agricultural production in Iran. The agricultural sector is vital in the Iranian economy highlighted by the Iranian government policy of self-sufficiency in food production. The agricultural sector is Iran's second largest employment provider and a significant contributing sector to the GDP. More than 33% of the total population of Iran is engaged in agriculture while the share of agriculture in GDP was 26% in 2000 [1]. In recent years with the rise in world energy prices the Iranian government has taken steps to reduce fuel and energy consumption. Rationing subsidized petrol and diesel for consumers and also taking measures to increase the efficiency of energy use to slow the growing energy demands in all sectors of the economy have been implemented. The implications of such policies in Iran have been a raised awareness in energy use.

Energy requirements in agriculture are divided into four groups: direct and indirect, non-renewable and renewable. Direct energy is required to perform various tasks related to crop production processes such as land preparation, irrigation, inter-

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culture, threshing, harvesting and transportation of agricultural inputs and farm produce [2]. Non-renewable energy includes diesel, chemicals, fertilizers and machinery, and renewable energy consists of human labour, seeds and manure [3]. Direct energy consumption in Iranian agriculture amounts to around 204.37 $PJ yr^{-1}$ (PetaJoule = 10^{15} J) which makes up 3.5% of the national consumption of fuel and electricity [4]. However a large part of the energy consumption in agriculture is in indirect form. Indirect energy consists of the energy used in the manufacture, packaging and transport of fertilizers, biocides and farm machinery [5]. Due to the low energy costs in Iran, no study has yet been conducted to evaluate the total direct and indirect consumption of energy in Iran's agriculture sector. Energy analysis of agricultural ecosystems seems to be a promising approach to investigate and assess the energy use efficiency, environmental problems and their relations to sustainability [6]. Thus, studying the energy use pattern to identify energy intensive areas of agricultural production seems essential. In order to achieve this goal it is necessary to analyse cropping systems in energy terms and to evaluate alternative solutions, especially for field crops, which cover around 13 million hectare of land [7] and account for more than 83.4% of the total cultivated area in Iran.

Over the past two decades production of field crops in Iran has significantly increased from 38.26 million metric tons (MT) in 1986 to 71.26 million MT in 2006 [7]. Iranian agriculture has increasingly aimed at grain cultivation, especially wheat and barley, which in 2006 occupied 65% of the entire agricultural area. There has been increasing use of fertilizers, chemical pesticides and new crop varieties, and this is the main reason for the increase in the yield per hectare. In the meanwhile the energy consumption in the agriculture sector has also increased.

The meaning of agricultural sustainability is strongly dependent on the context in which it is applied [8]. The present article will concentrate on agricultural sustainability in Iran from an energy use perspective. The aim of the current study is to verify the sustainability of this increased production by

- evaluating the energy performance of Iranian agricultural system;
- assessing trend of agricultural inputs and outputs over the years in energy terms;
- determining the energy efficiency of all field crops produced nationally.

Internationally there have been numerous studies conducted on energy consumption of different crops and many calculations of energy output/input ratios of different agricultural ecosystems have been made [3,9–14]. These output–input ratios are difficult to compare because they are calculated for a limited period (1 year), or they include only part of agricultural production or agricultural conditions which differ decisively in climate, types of soil, technology and political traditions [15]. There have been a few studies pertaining to the input–output energy analysis of whole agricultural systems. Ozkan et al. [5] reported that the output–input energy ratio of Turkey has decreased in the 25-year study period leading to year 2000. Alam et al. [16] reported that the rate of increase in agricultural inputs has not been met by the same rate of increase in agricultural production. This resulted in a decline in energy efficiency of Bangladeshi agriculture over the years. Schroll [15] proposed reduction of fossil energy and fertilizer application together with raising the plant component of human food as ways of increasing the output–input ration of Danish agriculture. In order to compare as many parameters as possible, the present investigation estimates the output–input energy ratio over a period of time for total Iranian agronomy production as it is the biggest section of the agricultural production in Iran.

2. Data and method

The investigation focuses on the calculation of the amount of all the inputs used for the production of agricultural crops and the crop yield per year during the period 1990–2006 of the Iranian agriculture. The investigation starts in 1990 because classified and usable statistical material covering the whole country regarding the amount of production inputs used, are available in this period of time.

For the growth and development, energy demand in agriculture can be divided into direct and indirect, renewable, and non-renewable energies [16]. Energy ratio of output–input is determined by calculating energy equivalents of yields gained from major crops produced and the inputs consumed.

In the calculation of the input energy, energy equivalents of human labour, machinery, electricity, diesel fuel, seed and fertilizer are considered. Energy output is calculated from production figures taken from the statistics of the average yields values of 15 crops which include all major quantitatively important crops grown in Iran. Energy content embodied in the crops is calculated based on the literature review and ASAE standards [17]. Energy equivalents of inputs and outputs are given in Appendix A.

The energy ratios in agricultural production are closely related with production techniques, quantity of inputs used by producers and yield level of crops along with environmental factors such as soil and climate. Therefore, there is a range of energy input and output relationships for the same crop depending on the region [18]. Thus, on a national scale it was decided to use a weighted average of all the inputs used and yields gained. In the study, 15 irrigated and 5 rain-fed crops were taken into account including irrigated: wheat, barley, maize, potatoes, tomatoes, sugar-beet, cucumber, cotton, lentils, chickpeas, peas, soybean, melon and water melon and rain-fed: wheat, barley, lentils, chickpeas and soybeans. The crops studied include all major irrigated and rain-fed field crops grown in Iran covering 85% of the cultivated land and 92% agronomy production in Iran.

The figures for the agricultural production have been produced mainly from the data provided by the Ministry of Agriculture of Iran (MAJ) [1,7,19]. An annual detailed report of the entire Iranian agriculture is published by the Ministry of Agriculture on the average amount and cost of all the inputs used by each crop on a national basis [19]. The data on labour force in agriculture were collected from the Statistical Yearbook of Statistical Centre of Iran [20] and data on agricultural wells from Ministry of Energy [4]. The data were converted into suitable energy units and expressed in $GJ\,ha^{-1}$. This way, considerable variation in the application of inputs between different parts of the country and individual crops is concealed. The study has also benefited from previous researches and studies conducted on energy analysis in agriculture.

The energy equivalents associated with labour vary considerably depending on the approach chosen; they must be adapted to the actual living conditions in the target region [21]. The labour energy equivalent in this study was calculated based on similar studies conducted in the region with comparable life styles. The amount of agricultural labour work required for all the operations of each crop were collected from the statistical year books on production cost [19]. These data were given in the form of labour-day/ha. Assuming 8 h of work a day [3,18,22,23] and considering 1.96 $MJ\,h^{-1}$ as human labour energy equivalent [3,12,18,23,24] the labour-day/ha was converted into $GJ\,ha^{-1}$. Considering the negligible share in the total input energy, animal power was omitted.

The data used for the study segregated the average amounts of insecticide, fungicide and herbicide used for each crop in each year. Chemical fertilizer consumption input data (N, P, K) and manure

were also collected [19]. The total energy input from fertilizer was calculated by summing the energy amounts of individual active substances. Seed is considered as a form of bioenergy input to agriculture. The amount of seed sown was available in the data for every crop [19].

Since there are no data available for diesel consumption for machinery used in agriculture, the total diesel energy input for the last year of the investigation was collected from field investigation using 75 hp tractors, taking into account the differences in the field operations of different crops. An estimation of the fuel consumption for all the field operations of each crop for every year of the study period was made based on the difference in mechanization level of each operation for each crop at different years as compared with the mechanization level of 2006.

In order to make an analysis of the embodied energy in the production of farm machinery and tractors it is assumed that the energy consumed for the production of the tractors and machinery will depreciate during their economical life time. The common tractor used in Iran is taken to be a 75 hp two wheel drive tractor with an average weight of 2500 kg [3,22]. The economic life time for agricultural machines was taken to be 13 years for the period of study based on unpublished studies by the Ministry of Agriculture (2006). Embodied energy in machinery is measured in terms of MJ kg^{-1}. To calculate the weight of machinery per ha the following equation is used:

$$TW = \frac{G \times W_h}{T} \tag{1}$$

where TW, total machinery weight ($kg\,ha^{-1}$); G, weight of tractor (kg); W_h, working hours required per hectare ($h\,ha^{-1}$); T, economic life time (h). The constant taken for the sequestered energy in tractor is taken 138 $MJ\,kg^{-1}$ [17].

The same method to estimate the fuel consumption in the early years of the study period was used to make approximations about the weight of machinery in the examined period.

Data on electricity use in agriculture is not available for each specific crop. Therefore, to calculate the amount of electricity used by each crop an estimation of the energy required to pump water for irrigating each crop was made. Average depth of wells used for agricultural purposes in Iran is reported to be 80 m [4]. A weighted average of the water requirement of each crop sown in different parts of the country was made and the energy required to pump the required amount of water was calculated using the following formula:

$$DE = \frac{\gamma g H Q}{\varepsilon_q} \tag{2}$$

where DE, direct energy ($GJ\,ha^{-1}$); γ, water density ($1000\,kg\,m^{-3}$); g, gravity ($9.81\,m\,s^{-2}$); Q, Net water requirement ($m^3\,ha^{-1}$); H, the total head (m); ε_q, overall efficiency, taken to be 0.18 [25]. Net water requirement is a weighted average of the different amounts of water required for optimum production of each crop grown in different parts of Iran [26], excluding precipitation.

There are enormous variations in energy equivalents reported in the literature. This is the result of differences in the methods of calculation and in the spatial and temporal system boundaries. Energy equivalents are not fixed once and for all. They must be adapted to local conditions (e.g. transport distances) and to changes in the manufacture of production means [27]. Based on the energy equivalents of inputs and outputs (Appendix A), the energy ratio (energy use efficiency), energy productivity, specific energy (energy intensity) were calculated [3,18,28]:

$$\text{Energy ratio} = \frac{\text{energy output}(GJ\,ha^{-1})}{\text{energy input}(GJ\,ha^{-1})} \tag{3}$$

$$\text{Energy productivity} = \frac{\text{crop yield}\,(kg\,ha^{-1})}{\text{energy input}\,(GJ\,ha^{-1})} \tag{4}$$

$$\text{Net energy gain} = \text{energy output}\,(GJ\,ha^{-1}) - \text{energy input}\,(GJ\,ha^{-1})$$

Specific energy is the inverse of Eq. (4). Energy output and net energy gain are crucial parameters when the availability of arable land is the limiting factor for plant production [21]. It must be noted that energy efficiency, productivity and intensity are based on the sequestered energy of fuel, fertilizers, machinery, human labour, etc. Solar energy, either as radiation or heat, was not taken into account, as it is considered as a free subsidy in the energetic or economic analysis of agricultural systems [29].

3. Results and discussion

Analysis is carried out on the energy input from various sources and the energy output of 15 field products on a hectare basis.

3.1. Field crop production

Data concerning the quantity of crops and area covered by type of crops appear in Table 1. The yields per hectare for all crops grown in Iranian agriculture have increased in the period concerned. While the increase in the average yields of tubers and cereals is tangible that of cotton is not significant. However, the increase has not been steady during the past two decades adversely affected during drought years as reflected by the decrease in the yield of cereals in 2000. There has been little change in the area under cultivation of different crops throughout the study period with cereals covering above 60% of total land showing their importance in Iranian agriculture.

Table 2 shows crop yields measured in $GJ\,ha^{-1}$, the agricultural area covered by the study and total agricultural area of Iran during the study period. The significant decrease in the total agricultural area in year 2000 is due to the depleting water resources after the year 1999 drought in Iran. As can be seen in Table 2, the highest and lowest output of $GJ\,ha^{-1}$ belongs to sugar beet and tomato/cucumber, respectively.

3.2. Analysis of energy inputs in Iranian agriculture

Energy inputs used in Iranian agriculture are shown in Table 3. Results show that irrigation energy was the most energy

Table 1
Quantity of crops, $kg\,ha^{-1}$ and area by type of crop in percentage of arable farmland 1990–2206.

Crops	1990	Area % 1990	1995	Area % 1995	2000	Area % 2000	2006	Area % 2006
Cereal	2400	70.8	2800	68.5	2500	63.1	3300	67.4
Seeds/pulses	1040	4.5	1230	8.8	1100	9.8	1400	7.6
Potato/onion	19000	1.6	22600	1.5	26700	2.0	31000	1.7
Tomato/cucumber	18500	1.2	21000	1.4	22000	1.9	29000	1.8
Sugar beet	24500	1.2	27200	1.6	26600	1.6	36100	1.4
Melon/watermelon	17600	1.7	15700	0.8	19100	1.3	23700	1.3
Cotton	2100	1.5	2000	2.0	2100	2.2	2500	0.9

Table 2
Crop yields, measured in GJ ha^{-1} for the whole country. Total agricultural area in 10^6 ha.

	1990	1995	2000	2006
Cereal	36	41	37	48
Seeds/pulses	17	21	18	23
Potato/onion	48	58	65	76
Tomato/cucumber	15	17	18	23
Sugar beet	88	98	96	130
Melon/watermelon	33	30	36	45
Cotton	25	23	25	29
Total output for whole Country (GJ ha^{-1})	31	35	34	44
Agricultural area covered by the study (10^6 ha)	10.41	10.43	8.40	10.64
Total agricultural area (10^6 ha)	12.62	12.31	10.27	12.96

Table 3
Energy input in Iranian agronomy (average of period 1990–2006).

Inputs	Sequestered energy (GJ ha^{-1})	%
Irrigation	13.8	40.0
Fertilizers	9.8	28.4
Diesel	4.8	13.9
Seed	3.5	10.1
Machinery	1.2	3.5
Labour	1.0	2.9
Biocides	0.4	1.2
Total energy	34.5	100

consuming operation of production with a share of 40%. The average amount of irrigation energy consumed per hectare is consistent throughout the study period (Table 4). Irrigation is commonly performed with furrows in Iran's agriculture and so far negligible areas of agricultural land (2%) have been facilitated with efficient irrigation installations such as drip and sprinkler irrigation systems of water distribution [4]. Irrigation was not the most energy intensive input in studies done on Turkish [14] and Bangladeshi [16] agriculture since a larger part of the crop water requirement is fulfilled by the higher annual precipitation in those countries as compared to the mostly arid climate of Iran with an average annual precipitation of below 300 mm [30]. However, energy input for irrigation was found to be as high as 40% for some crops in Antalya region of Turkey [12].

Fertilization accounted for 28.4% of energy inputs mainly due to high-energy sequestered in N fertilizers which were used extensively. The amount of fertilizer energy input increased from 8.23 to 11.31 GJ ha^{-1} in the last 17 years (Table 4). The share of N fertilizer out of the total fertilizer energy was consistently above 65% during this period while that of manure energy was less than 2%. Nitrogen fertilizer application increased from an average of 168 kg ha^{-1} in the first quarter of the study period to 209 kg ha^{-1} in the last quarter. There are several reasons attributed to the increase in fertilizer application including insufficient availability and higher cost of manure compared to chemical fertilizers, tangible increase in yield achieved by increased application of fertilizers, increased local production and a 3-fold increase in the distribution of subsidized fertilizers from 1990 to 2006. Similarly in a study on Turkish agriculture, the amount of fertilizer energy input rose from 41% of the total energy in 1975 to 48% in year 2000 [5]. Similar results have been frequently reported on the share of fertilizer energy in the production of single crops [3,31,32].

Table 4
Energy input and output values in Iranian agriculture for the period 1990–2006 (per hectare).

	Years			
	1990	1995	2000	2006
Irrigation (GJ ha^{-1})	13.84	13.84	13.84	13.82
Fertilizers (GJ ha^{-1})	8.23	8.56	9.45	11.31
Diesel (GJ ha^{-1})	4.90	4.26	4.63	5.44
Seed (GJ ha^{-1})	3.10	3.35	3.54	3.81
Machinery (GJ ha^{-1})	1.23	1.03	1.11	1.29
Labour (GJ ha^{-1})	0.85	1.00	1.06	1.02
Biocides (GJ ha^{-1})	0.25	0.33	0.38	0.51
Total input energy (GJ ha^{-1})	32.40	32.37	34.01	37.20
Total output energy (GJ ha^{-1})	30.85	35.32	34.42	43.68
Energy ratio	0.95	1.09	1.01	1.17

The results in Table 4 show that diesel fuel energy increased from 4.90 GJ ha^{-1} in 1990 to 5.44 GJ ha^{-1} in 2006. The increase in the diesel fuel consumption is due to the increase in agricultural mechanization index from 0.30 kW ha^{-1} (0.40 hp ha^{-1}) in 1990 to 0.50 kW ha^{-1} (0.67 hp ha^{-1}) in 2006 [4]. Agricultural mechanization index is a ratio of the available mechanical power to the total agricultural land. The inconsistency observed in the increase of diesel energy stems from differences in agricultural practices and the type of machinery used. The high share of diesel energy among the inputs is partly due to the fact that agricultural land is traditionally tilled with the high energy consuming moldboard ploughs twice in every year. Moreover the availability of cheap subsidized diesel fuel (0.016 USD L^{-1} in 2006) along with using depreciated machineries contributed to wasteful consumption. The results of the sequestered energy in machinery are in line with the results of the diesel fuel consumption and show a steady increase during the study period (Tables 3 and 4).

Human labour energy while being an important and also an expensive input in the production process makes up for less than 3% of the total energy input. The results show an increase in the agricultural labour energy for the period under study. Even though, according to the statistics [20], the active agricultural population decreased during the past 17 years, the amount of labour energy consumed per hectare increased. The reason for this increase was utilization of inexpensive illegal migrant labour force (mostly from Afghanistan) in the agricultural sector of Iran during the period 1990–2003 which were not accounted for in the official national statistics. Therefore, despite the increase in the diesel consumption during the studied period there was also an increase in the labour energy.

From Table 3 it is shown that biocides were the least demanding energy input in Iran's agriculture with 0.40 GJ ha^{-1} (only 1.2% of the total energy input), considering 295, 58 and 115 MJ kg^{-1} for the sequestered energy in herbicides, insecticides and fungicides, respectively [17]. As can be seen from Table 4, the amount of biocide energy doubled during the past 20 years. Biocide energy input in agricultural production was calculated as 254.01×10^6 J ha^{-1} in 1990 and it reached 506.99×10^6 J ha^{-1} in 2006, with an increasing trend in use. Herbicides were the most commonly used biocide in the early years of the study, however with the increase in the import of fungicides and insecticides and their subsidized distribution, the use of chemicals increased significantly. In view of the relatively small contribution that plant protection agents make to the energy balance (Table 3), their importance should not be neglected as there is risk of environmental damage. The growing use of biocides highlights the need to act towards regulation of chemical use through setting of legislations. In recent years, subsidies on biocides have gradually been removed in Iran however there are yet no regulations to limit biocide application.

Seed energy accounts for 10.1% of the total energy input per ha^{-1} (Table 3). Over the years 1990–2006, on average, 75% of seed were sown manually or by spreaders [19] showing that precision sowing is still negligible in Iranian agriculture. Thus, the seed energy ha^{-1} shows an increasing trend from 3.10 to 3.81 GJ ha^{-1}.

Table 5
Energy ratio of major crops in Iran's agronomy (average for period 1990–2006).

Crops	Yield (t ha^{-1})	Energy ratio
A. Irrigated crops		
Wheat	3.2	1.32
Barely	2.8	1.22
Maize	6.6	1.81
Potato	21.7	0.85
Onion	29.3	0.86
Sugar beet	28.9	1.77
Lentil	1.0	0.70
Pea	0.4	0.73
Chickpea	1.6	0.68
Melon/watermelon	19.0	0.93
Soybean	2.0	1.78
Cucumber	18.1	0.38
Tomato	27.7	0.47
Cotton	2.2	0.49
B. Rain-fed crops		
Wheat	0.9	1.20
Barley	0.9	1.33
Lentil	0.4	1.30
Pea	0.4	1.08
Soybean	1.7	4.46

3.3. Energy ratio analysis of major crops in Iranian agriculture

Average yield and energy ratio of all the major crops in Iranian agriculture for the period 1990–2006 is shown in Table 5. As indicated in the table the highest energy ratio belongs to rain-fed soybean with 4.46. Irrigated and rain-fed soybean yields are 2.0 and 1.7 t ha^{-1}, respectively yet the amount of input energy for irrigated soybean is much higher thus, resulting a lower energy ratio. Similar energy ratio values were reported in Italy [28] and India [23,33]. From Table 5 it is shown that the least energy efficient crop in Iran's agronomy is cucumber with an energy ratio of 0.38, considering 1.0 MJ kg^{-1} as the energy equivalent of cucumber (Appendix A). Lower output of open field cucumber (average of 18.1 t ha^{-1} and high demand for energy intensive inputs such as fertilizer and irrigation are the causes of the low energy ratio. Ozkan et al. [14] also reported a low energy ratio of 0.76 for green house grown cucumber in Turkey.

Energy ratio of all rain-fed crops in Iran's agronomy is above 1 while less than half the irrigated crops are efficient in terms of energy use, showing the importance of irrigation energy in Iranian agriculture.

The average values of energy input and output, energy ratio, specific energy, energy productivity and net energy gain of Iran's agronomy products are tabulated in Table 6. Mean energy ratio (energy use efficiency) was calculated as 1.07, while the energy ratios for different years of the study period are shown in Table 4. As shown in Table 4, energy ratio rose from 0.95 to 1.17 during the study period. Thus energy ratio in Iranian agriculture shows an increasing trend from 1990 to 2006, with the exception of the decline in 2000 due to drought. In Turkey, Ozkan et al. [5] reported a decreasing output–input ratio from 2.23 to 1.18 for the period 1975–2000. Both input and output energies in Iranian agriculture were lower than that of Turkish agriculture. Schroll [15] also reported a decline in the energy ratio of Danish agriculture from 3.9 in 1936 to 1.0 in 1990.

Table 6
Energy parameters in Iran's agronomy (average for 1990–2006).

Items	Unit	Value
Energy input	MJ ha^{-1}	34441
Energy output	MJ ha^{-1}	36876
Energy ratio	–	1.07
Specific energy	MJ kg^{-1}	3.69
Energy productivity	kg MJ^{-1}	0.27
Net energy gain	MJ ha^{-1}	2436
Renewable energy input[a]	MJ ha^{-1} (%[c])	4513 (13.1)
Non-renewable energy input[b]	MJ ha^{-1} (%[c])	29927 (86.9)

[a] Includes human labour, seeds, manure.
[b] Includes diesel, chemical, fertilizers, machinery.
[c] Indicates percentage of total energy input.

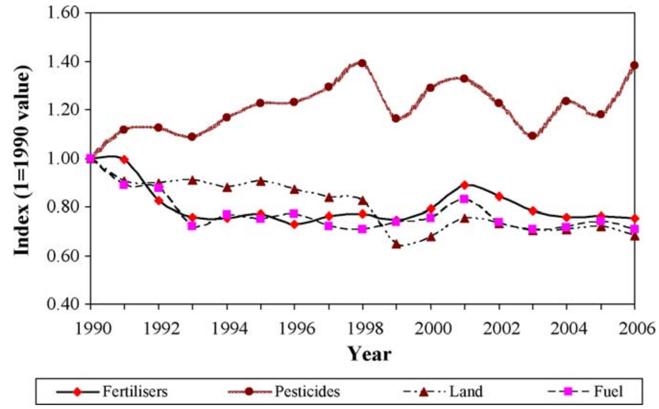


Fig. 1. Agricultural inputs per unit of output in Iran's agronomy sector.

The average energy productivity of farms was 0.27 which means that 0.27 unit output was obtained per unit energy (Table 6). Energy productivity rose from 0.22 in 1990 to 0.31 in 2006 reflecting improving efficiency in production in Iran's agriculture over the years. Calculation of energy productivity rate is well documented in the literature for single crops such as stake-tomato (1.0) [10], cotton (0.06) [18], potato (0.35) [3].

A maximum net energy gain is desirable when the land is used to produce renewable energy [34]. The average net energy gain value is positive showing the overall sustainability of Iran's agriculture. Specific energy (energy intensity) is a measure of the environmental effects associated with the production of crops (consumption of fossil fuel and other resources, emission of carbon dioxide and other combustion gases). Therefore, this parameter can be used to determine the optimum intensity of land and crop management from an ecological point of view [21]. The average amount of energy required to produce 1 kg of crop was calculated as 3.69 MJ.

Fig. 1 shows the amount of major inputs used to produce one unit of output, with 1990 as the base year. Since inputs are often expensive and, like biocides and fertilizers, may have environmental consequences, input trends are an important indicator of the long-term health of the agricultural enterprise and the level of its environmental impact. A decreasing input index results because the input is used more efficiently by farmers or because of advances in agronomy. As shown in Fig. 1 while less and less land, fertilizer and fuel are required to produce the same amount of agricultural output, an increasing amount of biocide is consumed per unit output compared to 1990. Fig. 1 indicates that the amount of land per unit of output reduced by 32% in 2006 compared to 1990.

Table 6 shows the distribution of total energy input as renewable and non-renewable forms. As it can be seen from the table, Iranian agriculture is heavily dependent on non-renewable energy sources (86.9%).

4. Conclusions

In an effort to determine the energy intensive areas of Iran's agronomy sector and evaluate its sustainability this study investigated energy use of inputs and outputs of 19 major irrigated and rain-fed agronomy field crops in Iran. The results revealed that both input and output energy have grown over the study period.

The total input energy value increased from 32.40 in 1990 to 37.20 GJ ha^{-1} in 2006. Similarly output energy increased from 30.85 in 1990 to 43.68 GJ ha^{-1} in 2006. In our study, energy ratio (output over input) for the Iranian agriculture was 1.07, considering only the main products. The energy ratio showed an increasing trend, meaning the increase in agricultural inputs has been accompanied by a larger increase in the outputs. Cucumber and rain-fed soybean had the lowest and the highest energy ratio in Iran's agronomy products with 0.38 and 4.46, respectively.

The energy input of irrigation (40.0%) followed by chemical fertilizers (28.4%), mainly nitrogen, had the biggest share within the total energy inputs. Biocide energy doubled during the study period however it still makes the least contribution to the total energy input. Due to increased mechanization of Iranian agriculture, fuel consumption rose by 10% during the study period.

Energy productivity (EP) has shown an increasing trend reflecting increasing energy efficiency. The average EP was calculated 0.27 kg MJ^{-1}. In terms of net energy gain, the results suggest a sustainable growth in Iranian agriculture as a whole; however 86.9% of the inputs come from non-renewable sources of energy. It was observed that with the exception of biocides, all inputs per unit of agricultural output reduced during the study period. Also with higher yields and improved agricultural practices, the unit of land used per unit of output reduced by 32% in 2006 compared to 1990. It can be inferred from the results that improvements in the irrigation efficiency together with promotion of targeted application of fertilizers can have a significant effect on the energy efficiency of Iranian agriculture. Advances in irrigation will also alleviate the effect of droughts on energetic parameters. Employment of more productive cultivars and more intense crop management will lead to higher outputs, thus a higher energy ratio.

Future research should combine energy analysis with long term economical analysis which further explains production patterns and highlights areas of agriculture with both economic and energy shortcomings. The present investigation of output–input energy ratio over time provides policy makers of Iranian agriculture with the possibility of selecting a realistic option for an energy ratio. To reach an ER of 2 seems a reasonable target to obtain, over, say, a 5 year period.

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Appendix A. Energy content of inputs and outputs

Item	Unit	Energy equivalent (MJ/unit)	Reference
A. Inputs			
Human labour	h	1.96	[3,18,22,35]
Machinery	kg	138	[17 (adapted), 22]
Diesel Fuel	L	47.3	[11,36]
Chemical fertilizers kg			
(a) Nitrogen (N)		78.1	[17]
(b) Phosphate (P_2O_5)		17.4	[11,17]
(c) Potassium (K_2O)		13.7	[17]
Organic manure	kg	0.3	[3,10,35]
Insecticides	kg	58	[13,17,37]
Fungicides	kg	115	[13,17,37]
Herbicides	kg	295	[13,17,37]
Seeds	kg		
Cereals and pulses	kg	25	[5]
Tuber	kg	14.7	[5,35]
Cotton	kg	11.8	[18]
Tomato/cucumber	kg	1.0	[5,10]
Oil seeds	kg	3.6	[5]
B. Outputs			
Cereals and pulses	kg	14.7	[5,12]
Tuber	kg	3.6	[5,13]
Melon/watermelon	kg	1.9	[5]
Cotton	kg	11.8	[18]
Tomato/cucumber	kg	0.8	[14]
Onions	kg	1.6	[5]
Potatoes	kg	3.6	[3,5,35]
Oil seeds	kg	25	[5]

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